In: Crop Protection Research Advances ISBN: 978-1-60456-040-4
Editors: E. N. Burton and P. V. Williams, pp. 163-181 

*Chapter 6*

# REDUCING THE UNCERTAINTY OF IPM ECONOMICS

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## ABSTRACT

Integrated pest management (IPM) refers to the systematic, repeated application of pest-surveillance and -control technology to reduce the economic impacts of diverse insects, pathogens, nematodes, weeds and animals that damage agriculture. Extensive literature describes complex IPM surveillance and intervention programs, with economic threshold (ET) and economic injury level (EIL) used to predict negative pest impacts and timely pest-control applications. Modeling provides an inexpensive, *a priori* way of studying key parameters for IPM economic analysis. Basically, five parameters determine IPM economics:

(1) crop value,
(2) pest-caused crop loss,
(3) cost of surveillance (i.e., both personnel and materials),
(4) cost of pest control (i.e., both personnel and materials) and
(5) effectiveness of the damage prevention or reduction.

Reducing uncertainty is a major goal of modeling, where uncertainty refers to a measure of variance associated with economic unknowns. Agriculture extension agents and farmers can benefit from the use of techniques that project a range of potential benefit-cost indices, which scope the uncertainty associated with potential costs and savings of IPM. This chapter:

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- reviews selected literature related to IPM and economic modeling,
- provides Excel XP® code (Microsoft® Corp., Richmond, Washington, USA) for use by extension personnel and farmers to estimate potential savings that can be recouped from timely pest-surveillance and pest-control expenditures and
- recommends key steps to improve the modeling of IPM economics.

## INTRODUCTION

Diverse insects, pathogens, nematodes, weeds and animals cause the loss of food and fiber during cultivation and storage (Pimentel, 1997). More than 40 years have elapsed since the terms "integrated control" and "integrated pest management" (IPM) were coined (Stern et al., 1959; Smith and van den Bosch, 1967). "Integrated control" involved applied pest control, both chemical and biological, which sought to manage pest populations in crops and habitats comprising wider agro-ecosystems (Stern et al., 1959). Later, IPM came to refer to the systematic monitoring of pests for the purpose of timely application of pest-control technologies to minimize crop damage (Cate and Hinkle, 1994; Kogan, 1998).

The IPM concept is rooted heavily in entomology (Kogan, 1998); few publications deal with IPM for mammals and birds (see Witmer, 2007). Research on insecticide use dominated the early literature, but subsequent determinations of pest resistance and environmental contamination led to less use of chemicals and a systems approach to pest management (Cate and Hinkle, 1994). Periodic surveillance of pest populations, greater use of biological controls and timely interventions of pest control became main elements of sustainable IPM (Cate and Hinkle, 1994; Kogan, 1998).

The concept of economic threshold (ET) provided a corollary to "integrated control" (Stern et al., 1959). It linked a pest density or pest population size to a negative economic impact upon crop production (Stern et al., 1959). Numerous articles were written about ET and economic injury level (EIL)—the amount of economic loss that a prescribed pest density or pest population will likely cause (See Higley and Pedigo, 1997). These studies often combined a specific ET with specific crop phrenology (Cochran, 1985; Wilson, 1985); whereas studies of EIL often invoked statistical regressions of damage between pest densities or populations and subsequent monetary losses (Higley and Pedigo, 1997; Stern, 1973; Stern et al., 1959).

IPM strategies are complex, involving a myriad of agricultural, biological, ecological, geographical, meteorological, pesticide, production, seasonality, species (pests and pest predators) and soil inputs (National Research Council, 1996). For example, a list of U.S. agricultural crops and activities consists of 7 dry bean/pea, 35 field (e.g., barley, corn, cotton), 29 fruit (e.g., apples, apricots, cherries), 6 nut (e.g., almonds, macadamia, peanuts), 13 specialty (e.g., peppermint, spearmint, tobacco), and 30 vegetable crops (e.g., artichokes, asparagus, tomatoes), plus > 25 farming activities (e.g., aquaculture, apiaries, eggs) (see National Agriculture Research Service, 2007). Inclusion of other inputs (i.e., genetic properties of seeds, geographic locations of fields, ecological habitats of pests and pest-predators, formulations of pesticides, daily patterns of precipitation and temperature, cultivation practices of crops and chemical characteristics of soils) precludes study of all possible permutations of IPM-related variables. Although numerous studies have been conducted to sort out two- and three-factor interaction effects among combinations of salient IPM-related variables for specific pests and crops (e.g., Ajeigbe and Singh, 2006; Coble et al., 1981; Cochran, 1985; Walter et al., 1984; Wilson, 1985), hundreds more are needed if such comprehensive strategies are to be devised. Optimally, IPM strategies seek to quantify specific interactions among a small set of key factors affecting an agro-ecosystem.

Intervention (timing) decisions are a key part of successful IPM programs and rely heavily upon economic considerations (Cate and Hinkle, 1994; Kogan, 1998). Cost-effective interventions require *a priori* knowledge of IPM benefit-cost relationships. State agriculture extension offices help farmers with regional strategies and timely pest-control applications, but many farmers fail to use these resources (Duffy, 1996). Extension agents often face difficulties in convincing farmers to adhere to an IPM strategy because they lack information about probable crop losses and profit impacts. Wide-area consistent pest control is crucial to IPM. Omission of even one farm within an area can allow pests to form reservoirs for renewed infestations. Analytical tools to aid extension agents in convincing farmers of pest-surveillance and pest-control decisions are sorely needed.

The objective of this chapter is to present a basic economic model of IPM and simplified procedures for examining the benefit-cost structure of potential IPM expenses and savings. Modern personal computers and user-friendly software make this objective attainable. Extension personnel and farmers utilize computers and spreadsheets to track IPM program, annual production, farm expense and farm profit data. This same equipment and software can be used to project economic indices of IPM—reduce the uncertainty of IPM expenditures and likely returns.

## SURVEILLANCE AND PEST CONTROL: THE PARADIGM

The annual surveillance and pest-control paradigm for agricultural crops and activities associated with IPM is illustrated in Figure 1. Seasonality factors typically lead to surveillance of pest populations and pest population growth or decline. The use of pest-control technologies is tied to pest density or population indices. The timing of pest-control determines the amount of recouped savings to be gained by preventing or reducing expected crop losses (i.e., damages) due to specific pests. These prevented losses become potential savings.

An example of this paradigm was recently reported for Australia (Ramsey and Wilson, 2000). Rodent "outbreaks" frequently cause agricultural and human health concerns in that country (Redhead, 1988; Redhead et al., 1985). Mouse plagues in grain belts of eastern and southern Australia are reported to occur in roughly four-year cycles, with economic damages of > 10 million Australian dollars (≈ 8 million in 2007 US$) incurred during each cycle (see Ramsey and Wilson, 2000).

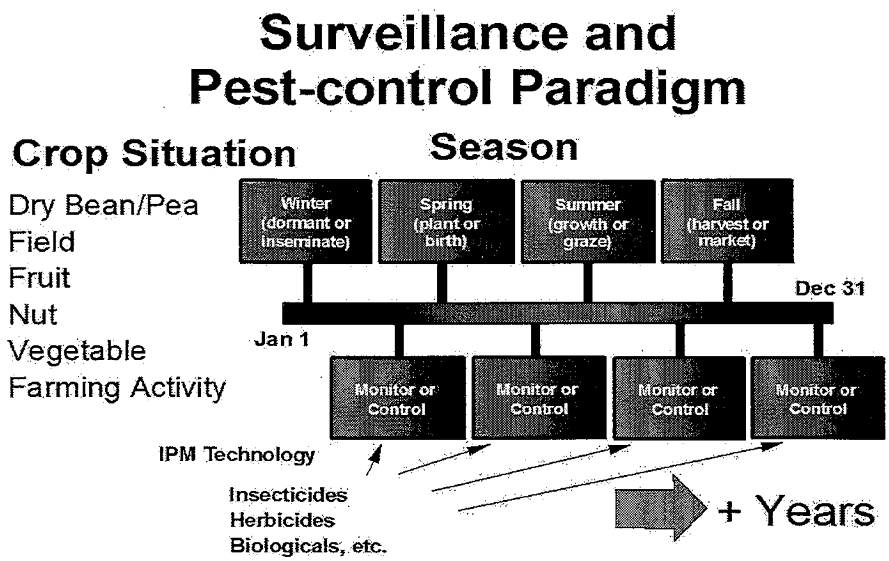


Figure 1. Schematic diagram that shows the complexity of variables and multi-variate interactions affecting IPM surveillance and pest-control schemes.

Three species of rodents are identified as pests in this situation: cane field rat (*Rattus sordidus*) in sugarcane, roof rat (*R. rattus*) in macadamia nut orchards and house mouse (*Mus musculus*) in cereal and oilseed crops. Extensive monitoring of rodent populations has led to the identification of four population phases of these rodents in crops: increase (post-winter breeding and crop growth), peak (spring to summer build up and crop maturation), decline (post-summer die-off and plant harvest) and low (over-winter low and crop and habitat dormancy). These phases of pest population dynamics (coincident with crop cycles) have been used to predict the effective timing of pest control and the amount of rodenticide bait applied (Ramsey and Wilson, 2000).

The effects of varied temporal interventions for rodent control within the four-phase cycle are shown in Figure 2 (Ramsey and Wilson, 2000). A threshold population size "D" is assumed to produce significant damage to the crop—somewhat analogous to ET and EIL. Successive intervention points of rodent control (bait application) before, at or after recognition (anticipation) of peak pest populations, with an assumed population reduction of 80 percent, results in less total damage and increased crop savings. More crop savings are attained if pest-control precedes the "damage" threshold and peak rodent population (Ramsey and Wilson, 2000). Although numerous ecological-habitat management (i.e., perimeter baiting to prevent crop invasion, post-crop stubble management, refuge management) and pest-control schemes (i.e., protection, active control or no action) were included in the study, this simple timing strategy based solely upon the expected build up of pest populations within and between crop and habitat cycles was proved cost effective for Australian farmers. If over-winter conditions do not favor pest outbreaks, pest surveillance can be curtailed (i.e., cost savings). Likewise, pest control can be limited if the surrounding habitats, pest species and expected population growth do not support a major rodent "outbreak" (i.e., cost savings).

Implied in this approach is the notion that farmers' (or governmental) surveillance activities and pest control actions will return potential savings by negating some portion of losses.

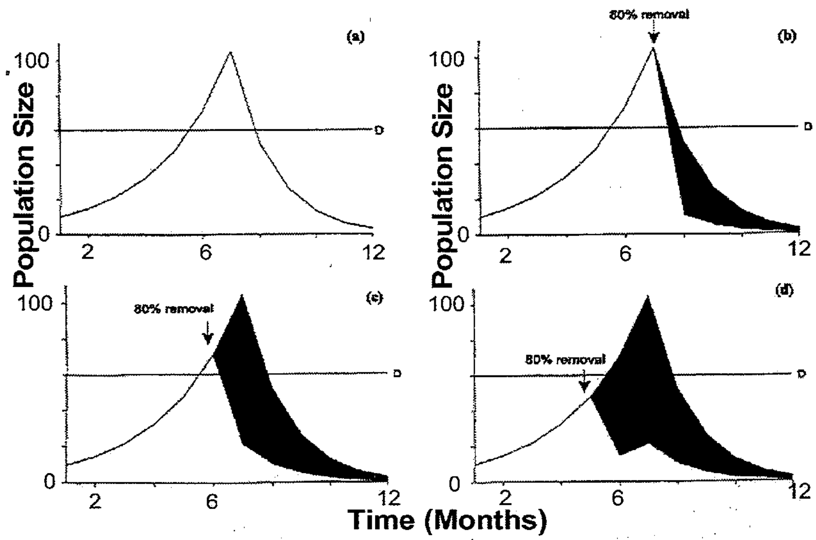


Figure 2. A composite set of graphs that show hypothetical results of the IPM model for rodent control in Australian crops. Successive functions show: (a—top left) hypothetical mouse population without control procedures, (b—top right) with 80% of the population removed at peak density, (c—lower left) with 80% removed when damage is first observed and (d—lower right) with 80% of the population removed in anticipation of future damage. (Reprinted with larger labeling from International Biodeterioration and Biodegradation, 45, D. S. L. Ramsey and J. C. Wilson, Towards ecologically based baiting strategies for rodents in agricultural systems. 183-197, 2000, with permission from Elsevier, Ltd.).

## ECONOMIC MODELING AND UNCERTAINTY REDUCTION

Models are mathematical (symbolic) expressions of natural phenomena (Burnham and Anderson, 2002). Descriptive, statistical (e.g., simple linear and multiple linear regression, non-linear regression, time series analysis and multivariate analysis), individual population and information transfer are sub-types of models (Burnham and Anderson, 2002). Obviously, a spectrum of complexity is represented by these model sub-types. Some models require extensive quantitative skill; whereas, others require limited mathematical knowledge (i.e., descriptive).

Simple linear and multiple linear regression statistical models characterize most IPM economics research (Higley and Pedigo, 1997). Traditionally, regression models have been used to quantify relationships between bi-variate or multi-variate factors involving pest-surveillance, crop-growth, crop-damage and IPM-cost data (See Higley and Pedigo, 1997). Simulation and "stand-alone" decision-making models have also been developed to aid with

IPM, using sophisticated mathematical and risk-analysis procedures to achieve optimal timing of pest control actions (See Clark, 1990; Coulson and Saunders, 1987; Teng, 1991).

The selection of parameters is the main step in model development (Burnham and Anderson, 2002). Parameters refer to general attributes of phenomena (e.g., pest-caused crop damage) that either cause or correlate with outputs (e.g., crop yield, benefit-cost ratio). Examples include: mean pest density per plant (#/plant), mean inter-plant spread rate (# plants/unit time), mean plant loss ($/plant), pesticide application frequency (#/agro-ecosystem) and insecticide spray rate (L/min). Variables are specific values of these parameters, which can be substituted into parametric expressions to assess computational predictions (e.g., mean 1.5 boll weevils/cotton square, mean 2 g loss/panicle of barley). Between 2 and 5 parameters comprise most models, but literally hundreds of variables can be inserted into models to assess the effects of selected parameters upon results, i.e., robust examination of the models and parameters via substitution and systematic replacement of specific values (Burnham and Anderson, 2002).

Modeling affords a unique approach to the study of IPM economics. Typically, assumptions are stated, parameters are selected, and independent variables are substituted for one or more iterative computations of an equation (Burnham and Anderson, 2002; Zerbe and Dively, 1994). The predictions, inferences and explanations gained in managing crop pests, deriving the benefits and costs of IPM and predicting potential economic savings from these interventions will ultimately determine model effectiveness.

Reducing uncertainty is a major goal of modeling (Zerbe and Dively, 1994). Uncertainty refers to the magnitude of dispersion in data sets due to economic unknowns (Zerbe and Dively, 1994). Unknown biological (e.g., pest population density, larvae hatch duration), crop (e.g., drought tolerance, compensatory growth), economic (e.g., crop market price, pest damage intangible costs), meteorological (e.g., minimum nighttime temperature, hail occurrence), pesticide (e.g., spray drift, crop leaf distribution), production (e.g., seed voids, plant root depth), seasonal (e.g., last frost, average dew point) and soil (e.g., carbon fixation, moisture level) variables interact to cause fluctuations in computed savings expected from IPM (Zerbe and Dively, 1994). Selections of such parameters for model development provide an inexpensive way of studying IPM.

The use of statistical confidence limits provides an analogy for uncertainty reduction. Confidence limits in statistical analysis rely on estimates of variance (i.e., sums of squared deviations of scores about an overall mean) for samples of fixed size ($n$); these limits can then be used to specify the probability (e.g., 0.95, 0.99) that future random samples of this size will yield a mean that is within these limits (Cochran and Cox, 1957).

Sensitivity analysis, decision tree analysis, worst-/best-case scenario, special contrived scenario and iterative projection exemplify uncertainty-reduction techniques (Burnham and Anderson, 2002; Zerbe and Dively, 1994). These methods assess how changes in a quantified variable (or variables) alter computations in other variables. For example, with sensitivity analysis, insertion of an increased or decreased value for one input variable "shocks" the model, producing a set of computations reflecting shifts in the output variable due to the chosen input variable (Zerbe and Dively, 1994). Examination of several such manipulations reveals how the other variables are affected by this input. Manipulations of an input variable can also be used in decision tree, scenario and iterative projection analyses to provide observations of how a single (or several) input variable(s) will change outputs. Similar to confidence limits, the uncertainty of outputs is decreased by observing iterative results for such manipulations. This chapter describes software that performs iterative projections of potential savings and benefit-cost ratios associated with prescribed IPM-related variables.

## ECONOMIC PARAMETERIZATION IN IPM

Five parameters constrain the economics of IPM: (1) crop value, (2) crop damage, (3) cost of pest surveillance (i.e., both personnel and materials), (4) cost of pest control (i.e., both personnel and materials) and (5) effectiveness of the damage reduction. These parameters can be used in six formulas to project economic limits and iterative benefit-cost values that reduce the uncertainty of IPM decisions and expenditures in specific crop and pest situations.

First, maximum crop valuation ($V_{max}$) specifies the upper monetary limit for a particular agriculture crop. Computation of this value is straightforward using expected, prior, average, etc. production and price data. The upper limit (US$) formula is:

$$V_{max} = Y \cdot P \cdot A, \tag{1}$$

where Y is crop yield (production/unit), P is price (US$ • production/unit) and A is the area considered in the agro-ecosystem or production (ha).

Second, estimated maximum potential crop saving ($S_{max'}$) attributed to IPM is a simple percentage of $V_{max}$. This refers to the portion of a crop that is projected to be damaged by pests. It is also the saving (US$) from IPM for that portion of a damaged crop which would be protected (i.e., harvested) if IPM was 100 percent effective. This value is the maximum return (US$) that can be recouped from IPM. The formula is:

$$S_{max'} = V_{max} \cdot D, \tag{2}$$

where $V_{max}$ is defined in Equation 1 and D is the amount of pest damage (%).

Third, the cost of pest surveillance ($C_{sur}$) requires an estimate of personnel and material charges for monitoring pest densities and populations during the crop cycle (or other prescribed time period). In many cases, this surveillance cost may be a fixed cost per event or per year (e.g., US$50/160 ha field, US$500/yr). Material costs associated with surveillance equipment (e.g., insect traps, live animal traps, cameras) are costs of equipment and supplies needed to conduct the pest monitoring. Together, these costs become the sum of the arithmetic products of price (US$) per surveillance event (including labor) times the number of events (US$/monitoring • events of surveillance) and price (US$) per equipment item times the quantities needed for pest density or population measurements (US$/equipment item • # of items for surveillance). This formula for IPM surveillance is computed as:

$$C_{sur} = (C_p \cdot M) + [(C_{ma} \cdot Q) + (C_{mb} \cdot Q) + \ldots (C_{mx} \cdot Q)], \tag{3}$$

where $C_p$ is the labor cost ($US), M is the number of monitoring events, $C_m$ is the combined material cost ($US) represented by $C_{ma}$, $C_{mb}$, ... $C_{mx}$ types of equipment or supplies and Q is quantity.

Fourth, the cost of pest-control application(s) ($C_{app}$) involves an estimate of personnel and material expenses. Personnel costs are derived as the product of the unit rate (US$/ha) times the area (i.e., US$/ha for labor • ha). Material costs associated with the pest management (e.g., insecticides, rodenticide baits, wasps) are based on commercial prices charged for the quantities needed according to a chemical registration (label) or other recommended guideline; these estimates are the product of the area (ha) times the price/unit/area (e.g., ha • US$/kg/ha, ha • US$/traps/ha). Of course, special adjustments are required for this calculation if IPM tools can be recycled (e.g., a pro-rated price would be needed to accurately depict the estimates for using insect traps if these were reusable). The application cost for a specific area is:

$$C_{app} = (C_{pl} \cdot A) + (C_{ml} \cdot A), \tag{4}$$

where $C_{pl}$ is the labor cost ($US/ha), $C_{ml}$ is the materials cost ($US/ha) and A is area (ha) as defined in Equation 1.

Fifth, an estimate of net potential crop saving ($S_{net'}$) is calculated as:

$$S_{net'} = (S_{max'} \cdot E) - (C_{sur} + C_{app}), \tag{5}$$

where $S_{max'}$ is defined in Equation 2, E is the projected effectiveness of the IPM surveillance and pest control written as a simple percentage (%) or decimal (0.00) and $C_{sur}$ and $C_{app}$ are defined in Equation 4.

Finally, a benefit:cost ratio (BCR) is computed. This ratio provides a value $< 1.0$ or $\geq 1.0$, which indicates that savings are smaller or equal to or larger than the IPM costs, respectively. This ratio is descriptive of relative costs and savings; it's constant across areas (ha):

$$BCR = [S_{max'}/(C_{sur} + C_{app})] + 1. \tag{6}$$

Although the cited formulas lack any mention of ET and EIL, a crude "threshold" of damage is implied, whereby gains on investments through spending for pest control become cost efficient. If projected returns of saved crop equal or exceed the expenses of surveillance and pest control then intervention is cost efficient. This is essentially a "break-even" analysis where a BCR of 1 is the threshold (see Duffy, 1996).

Of course, economic projections involving IPM to target a given pest will not avoid losses due to other pests affecting the same crop. The presence of two or more pests in a geographic locale compounds potential damage (losses) in unique, often unpredictable ways. Computations of potential crop savings and IPM expenditures must be combined for multiple pest species affecting a single crop. Control of a single pest in a multi-pest situation will lower cost efficiency—damage of some pests will go on unmitigated. Thus, despite the complex interactions alluded to earlier (i.e., among agricultural, biological, ecological, geographical, meteorological, pesticide, production, seasonality, pest and pest-predator species and soil variables or among pest-control methods and applicators), cost efficiency of IPM in the current context is viewed as a simple gain in yield of an undamaged portion of crop.

## ITERATIVE PROJECTIONS

Iteration involves systematically changing one variable at a time, while keeping the other variables in a model fixed—systematically computing outcomes for all combinations of the selected variables. For example, to compute iterations of the model in Equation 5, i.e., BCR = $[S_{max'}/(C_{sur} + C_{app})] + 1$, for spraying of cotton bollworms (*Heliothis zea*) over 15,000 acres of crop using two pesticide applicators that will charge \$3.00/acre and \$5.00/acre, respectively, with assumed 30 percent and 20 percent loss of cotton would require four computations (i.e., \$3.00/acre at 30% loss, \$3.00/acre at 20% loss, \$5.00/acre at 30% loss and \$5.00/acre at 20% loss).

Iterative projections of the BCRs associated with the previously described economic model helps to reduce uncertainty about pest-surveillance and -control decisions. Insertion of specific variables for crops, field sizes, pest damages and IPM labor and material charges into economic models can be programmed using spreadsheet code. Successive "runs" of the spreadsheet can provide systematic estimates of costs and savings for diverse pest-crop scenarios using combinations of variables for model parameters.

## SAMPLE PROJECTIONS

A vertebrate-pest scenario is provided to illustrate the use of iterative benefit-cost projections and uncertainty reduction in IPM. This sample is based on empirical literature (Babińska-Werke 1978, 1979; Tertil, 1977; Sterner, 1999, 2002; Sterner et al., 1996).

Voles (*Microtus* Spp.) are small, ubiquitous rodents that damage alfalfa (*Medicago sativa*) directly by foraging, but also indirectly due to the creation of "runways" (i.e., above-ground paths between burrows), which degrade plants and allow weed growth to occur. It has been shown that dense vole populations of 145 to 682 rodents/ha can reduce alfalfa biomass as much as 9 to 60 percent (Tertil, 1977). Zinc phosphide ($Zn_3P_2$; Chemical Abstract Series 1314-84-7) is a rodenticide registered for vole control in alfalfa crops in the U.S.; the registration allows $\leq$ 2% $Zn_3P_2$ grain baits (e.g., steam-rolled oats) to be spread onto the dormant crop at $\leq$ 11.2 kg/ha ($\leq$ 10 lbs./ac.) (See Sterner et al., 1996).

To provide a framework for modeling an IPM decision, a total of 420 iterative (combinatorial) estimates of net crop savings and BCRs are computed for six levels of crop losses (i.e., 5, 10, 15, 20, 25 and 30%), seven possible bait-effectiveness values (i.e., 0.70, 0.75, 0.80, 0.85, 0.90, 0.95 and 1.00) and 10 possible labor (applicator) fees (i.e., US \$1, \$2, \$3, \$4, \$5, \$6, \$7, \$8, \$9 and \$10/ha). The area (field) is 64.8 ha (160 ac). The surveillance cost of personnel ($C_p$) is set at \$2.00/ha for pest monitoring during the crop cycle; whereas, the materials cost ($C_m$) for surveillance supplies is \$0.30/ha for vole tracking tiles (i.e., ink covered vinyl tiles used to monitor foot prints and tail drags of rodents) during the crop cycle; the IPM application cost for personnel ($C_{p1}$) and materials ($C_{m1}$) is set at \$1.00/ha and \$3.15/ha, respectively. These IPM materials can be further divided into two costs: a single pre-bait application of untreated grain bait distributed at $\leq$11.2 kg/ha to assure sufficient ingestion of the rodenticide later, which costs \$0.42/kg, and a single rodenticide grain bait application of $\leq$2% $Zn_3P_2$ on grain baits, which costs \$2.73/kg (i.e., the use of pre-bait has been shown to improve ingestion of the subsequent $Zn_3P_2$ bait; Sterner, 1999). For computation purposes, the surveillance and pest-control materials costs are combined [i.e., \$0.30/ha for surveillance tracking tiles and \$3.15/ha at 11.2 kg/ha rate for pre- and $Zn_3P_2$-baits (\$35.28/ha for baits) equals \$35.58/ha total material charges]. Alfalfa yield is set equal to 7.77 metric ton (Mton)/ha and the alfalfa market price is assumed to be \$100.33/Mton.

The following formula replacements provide specific computations for the mathematical expressions described earlier:

$V_{max}$ (US\$) = [Y (7.77 Mton/ha) • P (US \$100.33/Mton) • A (64.8 ha)]
= \$50,516;

$S_{max'}$ (US\$) = [$V_{max}$ (US\$) • D (5, 10, 15, 20, 25, or 30%, respectively)]
= \$2,526, \$5,052, \$7,577, \$10,103, \$12,629, \$15,155, respectively;

$S_{net'}$ (US \$) = {[ $S_{max'}$ (US\$) • D (5, 10, 15, 20, 25 or 30% loss, respectively) • E (0.70, 0.75, 0.80, 0.85, 0.90, 0.95 or 1.00, respectively)] - [$C_p$ (US \$1, 2, 3, 4, 5, 6, 7, 8, 9 or 10 • 64.8 ha) + $C_m$ (US \$0.30/ha for vole tracking tiles • 64.8 ha) + $C_{pl}$ (US \$1, 2, 3, 4, 5, 6, 7, 8, 9 or 10 • 64.8 ha) + $C_{ml}$ (US \$3.15 for pre- and $Zn_3P_2$ baits • 64.8 ha)]}
= \$220, \$2,746, \$5,272, \$7,798, \$10,323, \$12,849, respectively (i.e., respective potential crop losses minus the total materials cost);

$C_{sur}$ (US \$) = {[A (64.8 ha) • $C_p$ (US \$2/ha)] + [A (64.8 ha) • $C_m$ (\$0.30/ha)]}
= \$129.60 + \$19.44
= \$159.04

$C_{app}$ (US \$) = {[A (64.8 ha) • $C_p$ (US \$2/ha)] + [ A (64.8 ha) • $C_m$ (\$0.42 • 11.2 kg/ha) + A (64.8 ha) • (\$2.73 • 11.2 kg/ha)]}
= \$129.60 + \$290.30 + \$1,981.32
= \$2,401.22

BCR = {[respective $S_{net'}$ (US\$) ÷ respective $C_{app}$ (US\$)] + 1}
= 0.612040 minimum (\$10/ha labor, 5% pest damage, 0.70 IPM effectiveness) to 6.573053 maximum (\$1/ha labor, 30% pest damage, 1.0 IPM effectiveness)

## EXCEL XP® CODE

Excel XP® code is provided on a computer disk contained in a packet inside the back cover of the book. This code performs iterations of the aforementioned computational formulas. Operators within the spreadsheet code are fairly transparent; however, those unfamiliar with Excel XP® will find standard manuals useful for verifying formulas and calculations (see Jacobson, 1997; Microsoft Corporation, 2007).

For ease of programming, personnel costs (i.e., $C_p$ and $C_{pl}$) and material costs (i.e., $C_m$ and $C_{ml}$) for surveillance and pest-control applications are derived using a unit rate per area variable (i.e., US\$/ha for personnel • ha). This is automatically computed for 10 fixed labor costs/ha (i.e., US\$1/ha to US\$10/ha), which is a main input/output variable of the computations. Thus, labor charges are not included as part of the input costs. Only costs of materials (i.e., $C_m$ and $C_{ml}$) are input, and these must be specified on a per ha basis and summed to derive a single combined materials cost per area for input ($C_m$/ha + $C_{ml}$/ha). For the sample analysis, fees for pest surveillance and bait broadcasts were set at \$2/ha each (i.e., \$2/ha for monitoring, and \$1/ha each for pre- and $Zn_3P_2$–bait applications). The input variable for materials consisted of \$0.30/ha for vole tracking tiles and \$0.42/kg (11.2 kg/ha rate) pre-bait and \$2.73/kg (11.2 kg/ha rate) $Zn_3P_2$ or a combined \$35.58/ha expense.

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A two-spreadsheet layout is used. Sheet 1 is an input sheet that specifies four key variables for the computations (i.e., the user simply types the respective entries into the appropriate rows of Column B on Sheet 1). Sheet 2 contains the main calculations and outputs. A 3-dimensional plot is also provided on Sheet 2; this graphs the BCRs for ease of use. Although metric measurements are used throughout this example, other units can be used as long as the changes are made throughout the variable entries and in the outputs (both tabular and graphical).

Sheet 1 contains a parameter block in Columns A and B, with inputs for Field size in Row 2, Yield in Row 3, Price in Row 4 and combined cost of IPM surveillance and pest-control per unit area (ha) materials in Row 5 (i.e., Row 1 is unused or blank). Figure 3 shows these entries for a 64.8 ha field size (160 ac.), which is expected to yield 7.77 Mton/ha of alfalfa at a market price of \$100.33/Mton and a combined IPM materials cost of \$35.28/ha.

| A | B |
|---|---|
| 1 | |
| 2 Field Size | 64.8 |
| 3 Yield | 7.77 |
| 4 Price | \$100.33 |
| 5 IPM materials | \$35.58 |

Figure 3. A matrix mimicking the Excel XP® layout and inputs for Sheet 1 of the BCR projections spreadsheet.

Sheet 2 consists of an 11-column (Columns A through K) by 68 row matrix (Rows 1 through 68) of inputs and outputs for the computations, plus a 3-D plot of the computed BCRs as a window below the tabular matrix (i.e., occupies approximately Rows 71 through 105). Figure 4 shows the truncated output for only the 30 and 25 percent damage for the sample problem (i.e., potential damage calculations for six damage variables are provided in a CD version of the code in a packet at the end of the chapter).

Column A of Sheet 2 contains key input/output variables. Specifically, Rows 9 through 13 contain Pest damage (%), Potential crop value, Potential crop loss, Application cost and Net savings entries (i.e., these appear as a single line in code, but the Figure shows 2 lines due to spacing); Rows 15 through 18 inclusive contain a repeat of Field size, Yield, Price and Product cost entries (i.e., the same as input on Sheet 1; and, Row 20 through 24 contain a second listing of Pest damage (%), Potential crop value, Potential crop loss, Materials cost and Net savings entries for 25 (%) damage. The user must be aware that IPM product materials are entered as the per unit area cost.

Column B of Sheet 2 provides the input of 30 (%) pest damage in Row 9, \$50,516 for Potential crop value in Row 10, \$15,155 for Potential crop loss in Row 11, \$2,306 for Materials cost in Row 12 and \$12,849 for Net savings in Row 13 (i.e., this is maximum potential net savings or maximum crop value minus 30% crop loss). Rows 15 through 18 repeat the selected variables of 64.8 ha, units, \$20.00 and \$100.00 for Field size (64.8), Yield (7.77), Price (\$100.33) and Materials expenses per area (\$35.58), respectively. A Pest damage input of 25 (%) is contained in Row 20, \$51,840 is repeated for Potential crop value in Row 21, \$12,629 for Potential crop loss is in Row 22, \$2,286 is repeated for Application cost in Row 23 and \$10,343 for Net savings occurs in Row 24 (i.e., this is maximum potential net saving or maximum crop value minus 25% maximum crop loss). This pattern of entries and calculations is then repeated for the four other damage inputs (i.e., 20, 15, 10 and 5 %) through respective rows until Row 68.

Column D of Sheet 2 provides successive Price/ha labor costs of from \$1 to \$10 in Rows 4 through 14 and Rows 15 through 24, respectively.

Columns E through K of Sheet 2 provide matrix outputs for the computed BCRs. Headers of these data columns occur in Rows 1 through 3 inclusive (i.e., Benefit-cost Ratios, IPM Effectiveness (%) and 100 to 70 as effectiveness calculations, respectively, above Columns E through K). Outputs in Rows 4 through 13 and Rows 15 through 24 contain the respective BCR computations.

Abbreviated Sheet 2 output for the sample analysis (i.e., only 30% and 25% damage output) is shown in Figure 4. Potential (maximum) crop value for a single cutting of a 64.8-ha alfalfa field at the \$100.33 price and 7.77 Mton/ha yield is \$50,516. Extrapolations of monetary loss projections for 25 and 30 percent damage are \$12,629 and \$15,155, respectively. Maximum potential (net) crop savings projections for 25 and 30 percent damage are \$10,343 and \$12,869, respectively. Minimum and maximum BCRs are 3.672240 and 6.573053 assuming 30 percent damage with a \$10.00/ha and a \$1.00/ha labor charge for 70 percent and 100 percent effectiveness of the monitoring, pre- and $Zn_3P_2$ bait outlays, respectively. Minimum and maximum benefit-cost ratios are 3.06020 and 5.477544 assuming 25 percent damage with a \$10.00/ha and a \$1.00/ha labor charge for 70 percent and 100 percent effectiveness of the IPM outlays, respectively.

| | A | B | C | D | E | F | G | H | I | J | K |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | | | Benefit-cost Ratios | | | | | | |
| 2 | | | | | IPM Effectiveness (%) | | | | | | |
| 3 | | | | Price/ha | 100 | 95 | 90 | 85 | 80 | 75 | 70 |
| 4 | | | | $1 | 6.57305312 | 6.244400464 | 5.915747808 | 5.587095152 | 5.258442496 | 4.92978984 | 4.601137184 |
| 5 | | | | $2 | 6.393363313 | 6.073695148 | 5.754026982 | 5.434358816 | 5.114690651 | 4.795022485 | 4.475354319 |
| 6 | | | | $3 | 6.223236562 | 5.912074734 | 5.600912906 | 5.289751078 | 4.97858925 | 4.667427422 | 4.356265593 |
| 7 | | | | $4 | 6.061929238 | 5.758832776 | 5.455736314 | 5.152639852 | 4.84954339 | 4.546446928 | 4.243350467 |
| 8 | | | | $5 | 5.908772865 | 5.613334222 | 5.317895579 | 5.022456935 | 4.727018292 | 4.431579649 | 4.136141006 |
| | Pest damage (%) | | 30 | $6 | 5.76316486 | 5.475006617 | 5.186848374 | 4.898690131 | 4.610531888 | 4.322373645 | 4.034215402 |
| | Potential crop value | | $50,516 | $7 | 5.624560606 | 5.343332576 | 5.062104545 | 4.780876515 | 4.499648485 | 4.218420455 | 3.937192424 |
| | Potential crop loss | | $15,155 | $8 | 5.492466651 | 5.217843318 | 4.943219986 | 4.668596653 | 4.393973321 | 4.119349988 | 3.844726656 |
| | Application cost | | $2,306 | $9 | 5.366434832 | 5.098113091 | 4.829791349 | 4.561469608 | 4.293147866 | 4.024826124 | 3.756504383 |
| | Net savings | | $12,849 | $10 | 5.246057201 | 4.983754341 | 4.72145148 | 4.45914862 | 4.19684576 | 3.9345429 | 3.67224004 |
| 14 | | | | | | | | | | | |
| | Field size | | 64.8 | $1 | 5.477544266 | 5.203667053 | 4.92978984 | 4.655912626 | 4.382035413 | 4.1081582 | 3.834280987 |
| | Yield | | 7.77 | $2 | 5.327802761 | 5.061412623 | 4.795022485 | 4.528632347 | 4.262242209 | 3.995852071 | 3.729461933 |
| | Price | | $100.33 | $3 | 5.186030468 | 4.926728945 | 4.667427422 | 4.408125898 | 4.148824375 | 3.889522851 | 3.630221328 |
| | Product cost | | $3558 | $4 | 5.051607698 | 4.799027313 | 4.546446928 | 4.293866544 | 4.041286159 | 3.788705774 | 3.536125389 |
| 19 | | | | $5 | 4.923977388 | 4.677778518 | 4.431579649 | 4.185380779 | 3.93918191 | 3.692983041 | 3.446784171 |
| | Pest damage (%) | | 25 | $6 | 4.802637383 | 4.562505514 | 4.322373645 | 4.082241776 | 3.842109906 | 3.601978037 | 3.361846168 |
| | Potential crop value | | $50,516 | $7 | 4.687133838 | 4.452777146 | 4.218420455 | 3.984063763 | 3.749707071 | 3.515350379 | 3.280993687 |
| | Potential crop loss | | $12,629 | $8 | 4.577055543 | 4.348202765 | 4.119349988 | 3.890497211 | 3.661644434 | 3.432791657 | 3.20393888 |
| | Application cost | | $2,306 | $9 | 4.472029027 | 4.248427576 | 4.024826124 | 3.801224673 | 3.577623222 | 3.35402177 | 3.130420319 |
| | Net savings | | $10,323 | $10 | 4.371714334 | 4.153128617 | 3.9345429 | 3.715957184 | 3.497371467 | 3.27878575 | 3.060200034 |

Figure 4. A matrix mimicking the Excel XP® outputs for Sheet 2 of the BCR projections spreadsheet, but truncated to show only the 30 percent and 25 percent portion of the calculations (i.e., the code contained on a computer disk (CD) in a sleeve at the end of the chapter will compute a six crop damage percentages (i.e., 30, 25, 20, 15, 10 and 5%).

Figure 5 presents the 3-dimensional plot of the BCRs for the sample analysis. As shown, BCRs increase transitively as vole-caused damage and bait effectiveness increase, but labor costs decrease. Additionally, BCRs of ≤1.0 (i.e., net crop savings ≤ application costs) occur invariably when vole-caused damage is 5%; whereas, crop losses of >10% consistently yield >2:1 returns on investments for monitoring and rodenticide baiting. As alfalfa damage exceeds 15%, lesser bait effectiveness (i.e., 80-70%) and greater application fees (US$8-10/ha) afford multiple (i.e., >3:1) returns on expenditures.

In summary, alfalfa growers expect multiple returns on expenditures for IPM. Under the current iterative projections, BCRs >2.0 (i.e., assuming full return on investment by the next cutting) occurs generally for alfalfa losses of ≥ 10%, depending on specific effectiveness and labor fees. This implies that pest monitoring and timing of pre- and $Zn_3P_2$-bait applications can affect crop savings and BCRs. Control of voles before adequate forage is available to sustain outbreaks (crop dormancy) or before populations begin to increase rapidly prior to the first cutting is one strategy suggested by these results.

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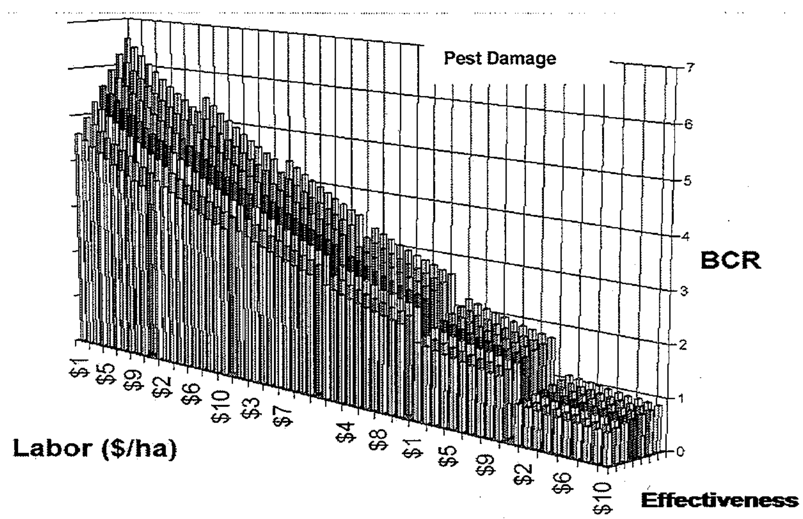


Figure 5. A 3-dimensional plot of the BCRs for sample projections as a function of pest damage, IPM effectiveness and labor cost produced by the Excel XP® projections spreadsheet (i.e., sets of pest damage plots appear for 5% increments starting with 5% to 30%from right to left; effectiveness ranges from 0.70 to 1.00 front to back on the z axis).

## GENERAL RECOMMENDATIONS FOR IPM MODELERS

The current five-parameter model characterizes the essence of IPM economics. Still, other modelers (e.g., agronomists, entomologists) will undoubtedly elect to delete certain parameters and include other parameters. For these scientists, the following recommendations seem relevant:

(1) Models, particularly simple mathematical models, should be constructed using empirical crop and pest data, but even rudimentary models of pest surveillance and potential BCRs from IPM intervention are useful. Models should be developed even when there are relatively few surveillance and pest-control data available. At the very least, these can then be used to determine the relative importance of parameters to model outcomes—reduce some uncertainty.

(2) Results from models should be used to direct the collection, or collation, of future data associated with the key parameters identified in the modeling effort. More emphasis should be placed on gathering data on variables showing high variance or uncertainty. Initial outputs provide evidence of model function and parameter importance. Focusing future data collections of highly variable or uncertain factors is analogous to stratified sampling in statistics—this is where major reductions in variance and uncertainty can be realized.

(3) An iterative cycle of new data, repeat analysis and review of outputs should characterize the modeling process. New data collections should be used to update initial models, to validate the deletion or inclusion of parameters and to construct altered and more-detailed models. These models can then be subjected to detailed uncertainty reduction methods and plans made for further data collections derived. Given the complexity of the pest surveillance and IPM strategies, the development of multiple candidate models is recommended for these projects. Novel approaches to selecting and including parameters in these models have been provided by the information-theoretic approach (Burnham and Anderson, 2002).

## CONCLUSION

Justification for IPM decisions is enhanced by *a priori* estimates of likely returns on investments. IPM requires uniform, large-area use to be effective. Failure to control pests in isolated fields or in a mosaic pattern across an agro-ecosystem will allow reservoirs of pests to reproduce and possibly re-infest crops. Agriculture extension agents (and farmers) can reduce the uncertainty of IPM expenses by computing likely costs and returns for extensive pest-crop scenarios. Evaluating iterative projections based on empirical IPM-related costs reduces the uncertainty of specific crop-pest strategies and expenditures. Advantages include: useful conceptualizations, predictions and inferences for selected pest-crop IPM schemes of interest to farmers, inexpensive examination of numerous IPM scenarios, and *a priori* estimates of likely returns on investments for selected IPM variables. At the very least, these outputs can then be used to determine the relative importance of cost variables to returns on investments. The current Excel XP® Code allows extension personnel (and farmers) to scope the specific benefits and costs of potential pest-surveillance and pest-control actions for diverse crop-pest situations and to devise customized IPM strategies based upon local economic conditions.

## ACKNOWLEDGMENTS AND DISCLAIMER

I am indebted to Mathew Kling who assisted with coding spreadsheet formulas and undoubtedly improved efficiency of the computations. John Baroch, Kathleen Fagerstone, Randahl Stahl and Gary Witmer provided helpful comments on the draft manuscript.

Use of trade names does not constitute endorsement by the US Government.

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